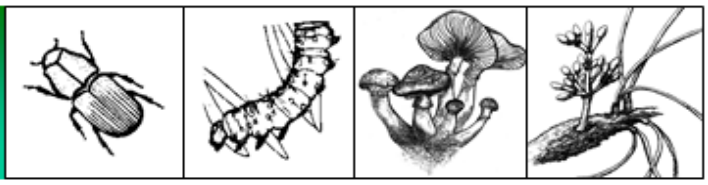
Forest Health Protection



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Young Ponderosa Pine Stand Conditions Associated with Resistance to Mountain Pine Beetle-Attack from 2010-2014 near Lake Como, Bitterroot National Forest

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Executive Summary

Forest health monitoring plots were established across 12 young ponderosa pine stands near Lake Como, Bitterroot National Forest, to assess precommercial thinning impacts on elytroderma needle disease (*Elytroderma deformans* (Weir) Darker). Stands were split to incorporate two paired treatments per stand as part of an incomplete block design. Treatments were 12x12 ft. residual-tree spacing (with and without pruning), 18x18 ft. spacing, and untreated controls. Treatments were implemented in 2004 and monitored over the next decade.

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins, MPB) activity occurred in the study area from 2010-2014. Resultant tree mortality was scattered and ranged from low to moderate severity (<10% and 10-30%, respectively) within affected portions of the study area and adjacent stands. After MPB activity subsided, 0.165-acre fixed plots were established to reconstruct forest attributes conducive to beetle-attack within monitoring plots.

MPB-caused mortality was highest in dense forested plots. Moderate-severity mortality occurred in plots starting at 124 stand density index (SDI) values or 54 feet^2 per acre of basal area (BA) while plots below these densities had minimal mortality. High-severity mortality occurred in plots starting at 172 SDI or 63 BA. Of note, the 18x18 ft. spacing treatment resulted in low levels of forest density 10-years post-treatment and had 0% of pines attacked by MPBs. This treatment had exposure to immediately adjacent beetle pressure from paired-plots.

Conclusions include: 1) stand densities associated with resistance to MPB-attack (quantified by < 10% mortality occurrence) were < 124 SDI or 54 BA; 2) 18x18-foot residual spacing treatments (97 SDI average) provided for resistance to MPB-attack for 10 years post-treatment while some 12x12 without pruning treatments (154 SDI average) experienced moderate (10-30%) and severe (>30%) mortality rates; and 3) pine stands with QMD as low as 4" DBH were impacted by moderate mortality and as low as 4.7" by severe mortality rates.

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Introduction

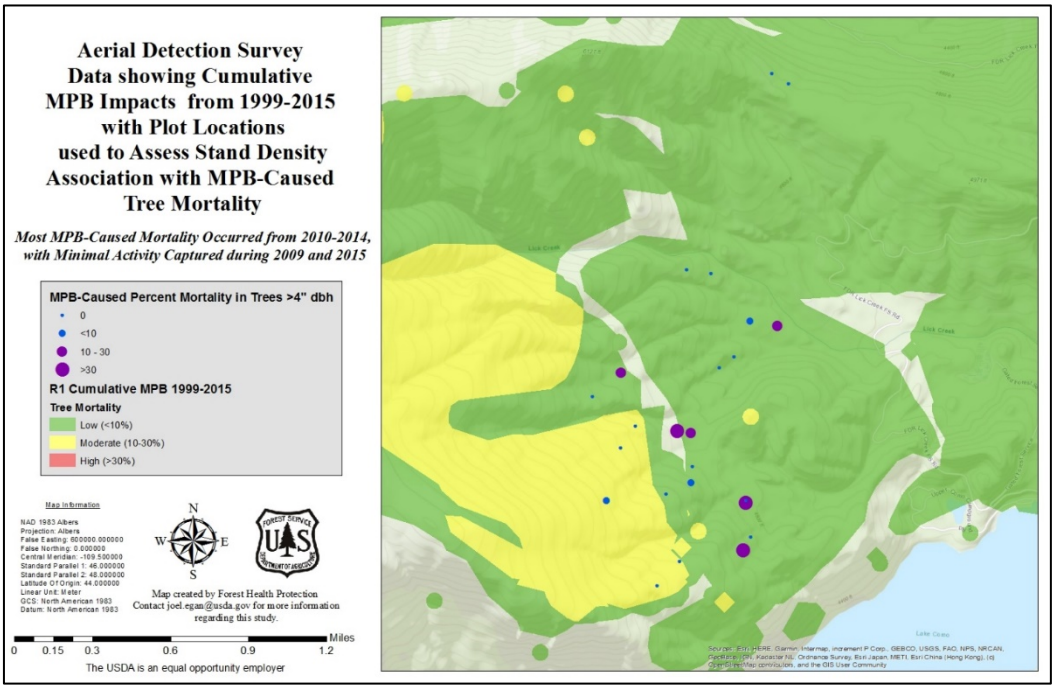

Figure 1. Map of study area and plot locations adjacent to Lake Como, MT. MPB-caused percent mortality (>4" dbh trees) near study area is estimated by aerial surveys and depicted by severity classes (green, yellow, and red). Plot data for percent mortality also depicted by severity with blue and purple dots.

Thinning to reduce forest density and promote resistance to bark beetles in pine systems has been identified as an effective treatment when conducted appropriately (Egan et. al 2014). While numerous studies support overall treatment benefits, specific residual density targets associated with resistance have varied in recent decades and are still being quantified (Oliver 1995; Egan et al. 2010; Fettig et al. 2007; Egan et al., *in preparation*). This study provides additional data points to help quantify such residual density targets by documenting forest structural conditions in western Montana pine systems that exhibited resistance to mountain pine beetle (*Dendroctonus ponderosae* Hopkins)-caused mortality when challenged by MPB population pressure.

This study was conducted after an outbreak of MPB occurred throughout the area near Lake Como on the Darby Ranger District, Bitterroot National Forest (BNF), and utilized a previously established thinning project. In this area, Forest Health Protection (FHP) and BNF staff established forest health monitoring plots in 2004 to investigate treatment effects of precommercial thinning activities on elytroderma needle disease (*Elytroderma deformans* (Weir) Darker) of ponderosa pine (Lockman & Hartless 2008; Smirnova et al., *in review*).

The original health monitoring plots were established in 2004 in twelve young ponderosa pine stands that had varying incidence of elytroderma infection. Each stand represented a block within the incomplete block experimental design, and each block was subdivided to incorporate two randomly assigned treatments per unit. Treatments were replicated six times and consisted of untreated controls, thinning to 12x12-foot residual spacing (with and without pruning), and thinning to 18x18-foot residual spacing. Within the center of each unit, 50 trees were identified and tagged to monitor for elytroderma infections over the subsequent 10 years. In controls, monitoring trees were identified using leave-tree criteria and given the same spacing targets that were implemented in the 12x12-foot residual spacing treatment units.

Results from the original study indicated that elytroderma infections ultimately increased across all treatments and the control; however, plots thinned to the 12x12-foot residual spacing had slightly reduced rates of intensification relative to the other treatments after 10 years (Smirnova et al., *in review*). Overall, this study indicated that treatments neither had substantial benefits to prevent further infections nor detriment by causing increased infections.

Our bark beetle study within this same area evaluated various forest structural densities to assess resistance to MPB-caused tree mortality. Specifically, we reconstructed forest density prior to the bark beetle outbreak to assess structural conditions associated with resistance to MPB-attack. Our objectives were to: 1) to describe forest attributes associated with elevated bark beetle-caused tree mortality; 2) identify structural conditions that suggest resistance; and 3) identify minimum stand diameter values associated with MPB-attack to inform criteria for FHP-administered Western Bark Beetle program.

Methods

Methods for plot location selection, establishment, and treatments implemented are detailed in Lockman and Hartless (2008). Plots were typically east-facing, with northeast to southeast aspects, while elevation varied from 1400 m (4600 ft) to 1707 m (5600 ft). Fixed plots were established in 2004-assigned units to capture forest density, composition, and mortality data in Fall 2016 and Spring 2017. Plots measured all trees within a .1661-acre plot (1/6.05th-acre) as measured with a 47.9-foot radius (adjusted for slope as-needed) which represents an equivalent occupancy area for 50 trees equally spaced in a 12x12 grid.

In each plot, every tree at least 4.5 feet in height was measured with surveys starting from plot center, oriented towards a northern aspect, with data collection progressing clockwise. Data collected included: the Lockman and Hartless (2008) study tree tag number, tree species, diameter at 4.5 feet in height, live/dead status, mountain pine beetle attack status, and snag status indicating recent-dead (> 2010) or older-dead (< 2010) as described in Egan et al. (2010).

Data processing

Forest attributes were calculated with commonly accepted protocols for basal area, quadratic mean diameter, and composition for all plots (Oliver and Larson 1996). Stand density index was calculated with the individual tree summation method described by Stage (1968). Mortality was depicted for both trees per acre and percent pine mortality (pines per acre killed / pines per acre > 4" DBH available).

To reconstruct attributes to the 2010 MPB outbreak initiation, trees killed between 2010 and the plot survey dates were included with live trees in density calculations. This method assumes minimal growth between 2014, when the MPB activity subsided, and the 2016/2017 measurement years. This assumption was validated as reasonable by assessing bi-annual diameter measurements that occurred throughout the sampling of the Lockman and Hartless (2008) study period.

Data interpretation

Inferential statistics were not conducted for these data as 1) the degree of exposure to bark beetle pressure varied across paired-treatments implemented through incomplete block design; 2) treatments resulted in different forest densities following growth and disturbance; 3) our analysis was concerned with structural density levels associated with resistance; and 4) assessing treatment effects on resistance to MPBs was not part of the original study's *a priori* objectives. As such, descriptive statistics are presented to document forest conditions associated with MPB susceptibility and resistance.

Results

Elevated MPB-caused mortality was detected from 2010-2014 based on FHP aerial detection surveys (ADS) (Figure 1). Resultant tree mortality was estimated with ADS typically at a low to moderate severity classes (<10% and 10-30%, respectively) (Figure 1). Plot data verified ADS estimates with a total mortality rate of 9.5% for pines ≥ 4" DBH sampled in plots. Proximity of paired-plot treatments within a

stand indicated majority of stands had exposure to immediate bark beetle population pressure from neighboring plots; however, minimal pressure challenged stands in which the 12x12 + Pruning treatment occurred.

The magnitude of MPB-caused tree mortality within study plots increased as forest density increased (Figure 2). The minimum forest density associated with various mortality severity classes provide data points on resistance failures. Forest densities < 124 SDI or 54 sq. feet per acre of basal area (BA) generally had virtually no mortality. This suggests these density levels were resistant to MPB-attack. The lowest density associated with moderate mortality (10-30%) was at 124 SDI and 54 BA while high mortality (>30%) rates were observed at 172 SDI and 63 BA. These data suggest <124 SDI densities were resistant to MPBs during this outbreak, 124-171 SDI were resistant to severe mortality but susceptible to low to moderate mortality rates; and >171 SDI was not resistant to MPB-caused mortality.

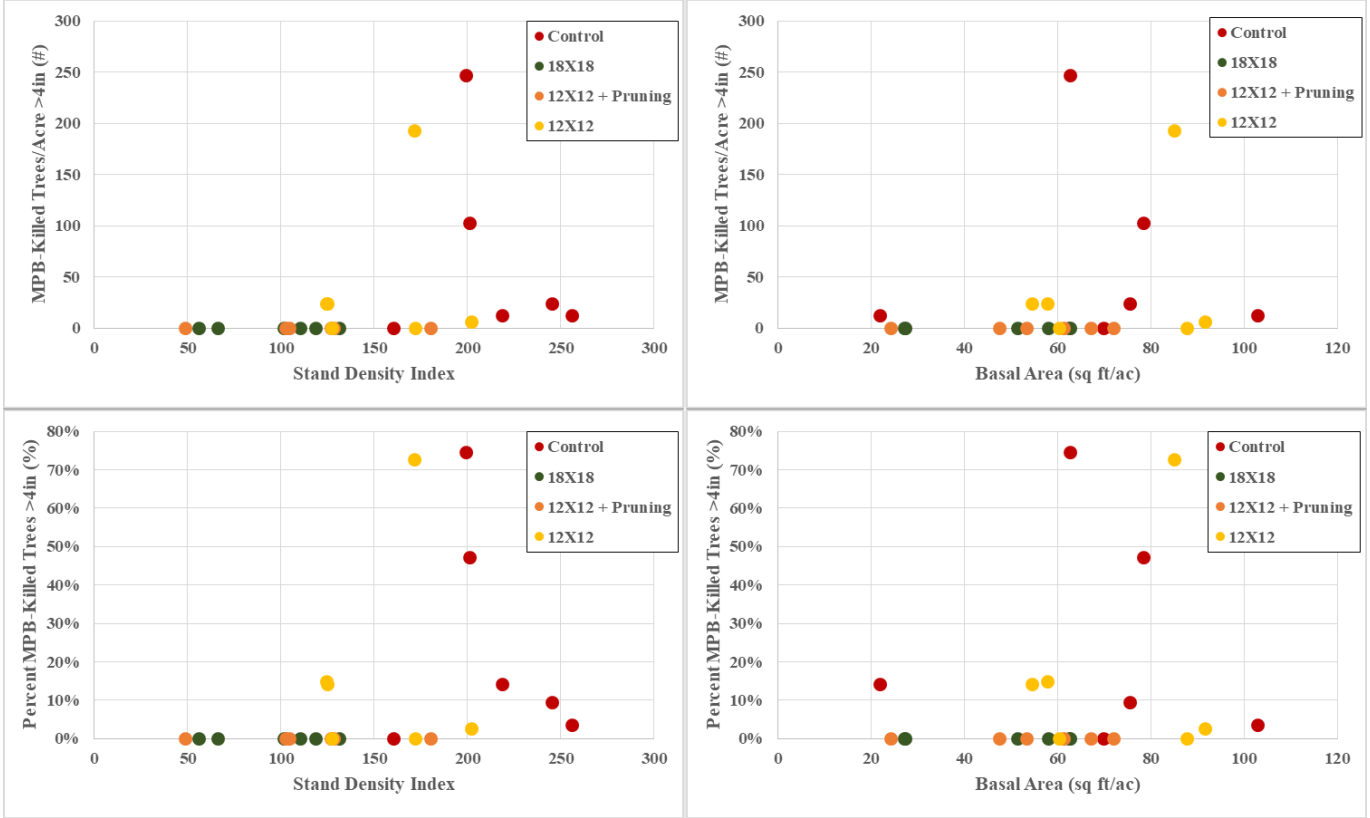

Figure 2. Scatter plots depicting MPB-killed pines (trees/acre and percent) at various stand densities (SDI and BA) documented within treatment plots from 2010-2014 in study area near Lake Como, MT.

Note, one control plot had moderate mortality (14%) associated with 20 BA, 3.4" QMD, and 220 SDI; however, this mortality rate was artificially amplified by very low number of pines > 4" DBH within the plot as only two trees were killed by MPBs.

Across treatments, stand density index (± M.S.E.) averaged 213 SDI (± 14) in controls, 154 SDI (± 13) in 12x12, 127 SDI (± 14) in 12x12 + Pruning, and 97 SDI (± 12) in 18x18. Plots that had 18x18 and the 12x12 + Pruning treatments had no trees killed by MPBs across all replicates. This occurred even where immediate beetle pressure challenged these plots from dense, adjacent plots with high levels of MPB-caused mortality.

Tree diameters associated with MPB-attack were evaluated across plots for individual trees. All plots contained >4" DBH host trees suitable for MPB colonization. MPB-caused mortality did not appear to have a relationship with quadratic mean diameter (QMD) as mortality occurred throughout the range of

QMD values calculated for study plots (Figure 3). Low-level mortality (4%) was documented in a plot with 3.4" QMD, moderate mortality in 4.0" plot, and severe mortality occurred in a plot with 4.7" QMD. The pre-commercially thinned plots all appeared to have greater QMD values relative to control plot values.

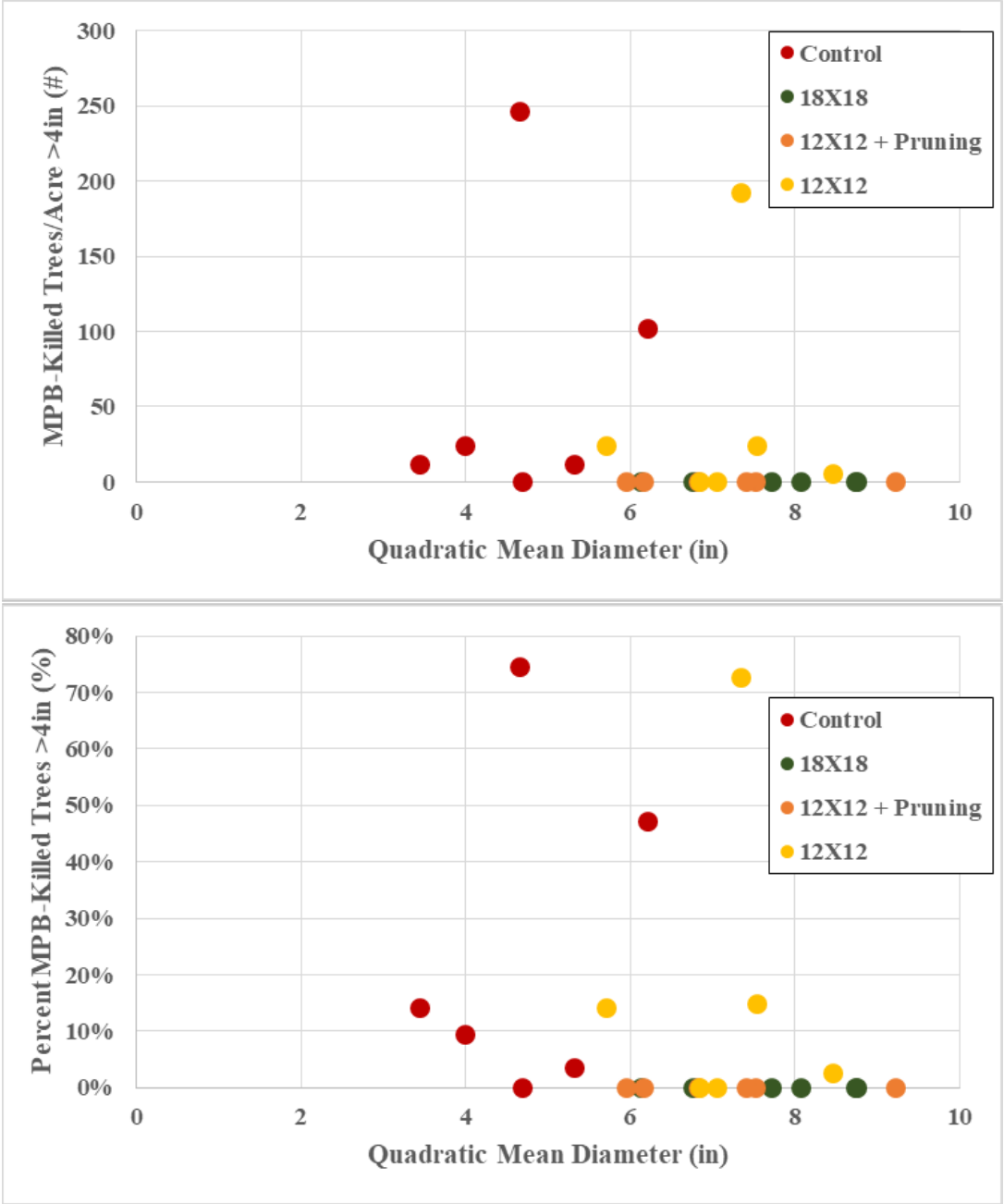

Figure 3. Scatter plots depicting MPB-killed pines (trees/acre and percent) across average diameter values within treatment plots from 2010-2014 in study area near Lake Como, MT.

At the tree-level, pine diameters across all study plots were skewed to smaller diameter classes (2-4.9” and 5-7.9”) being most abundant (Figure 4). MPB-attacks occurred in smaller diameter classes only and all trees ≥14” were unattacked. Within the 2-4.9” and 5-7.9” diameter classes, mortality was disproportionate and did not follow the distribution of available host. Trees in the 2–4.9” diameter class were attacked less than would be expected from their occurrence while trees in the 5-7.9” class were attacked more. Trees in 8-10.9” and 11-13.9” diameter classes were attacked nearly in proportion to their availability across study area trees. Trees in diameter classes ≥ 14” were not attacked.

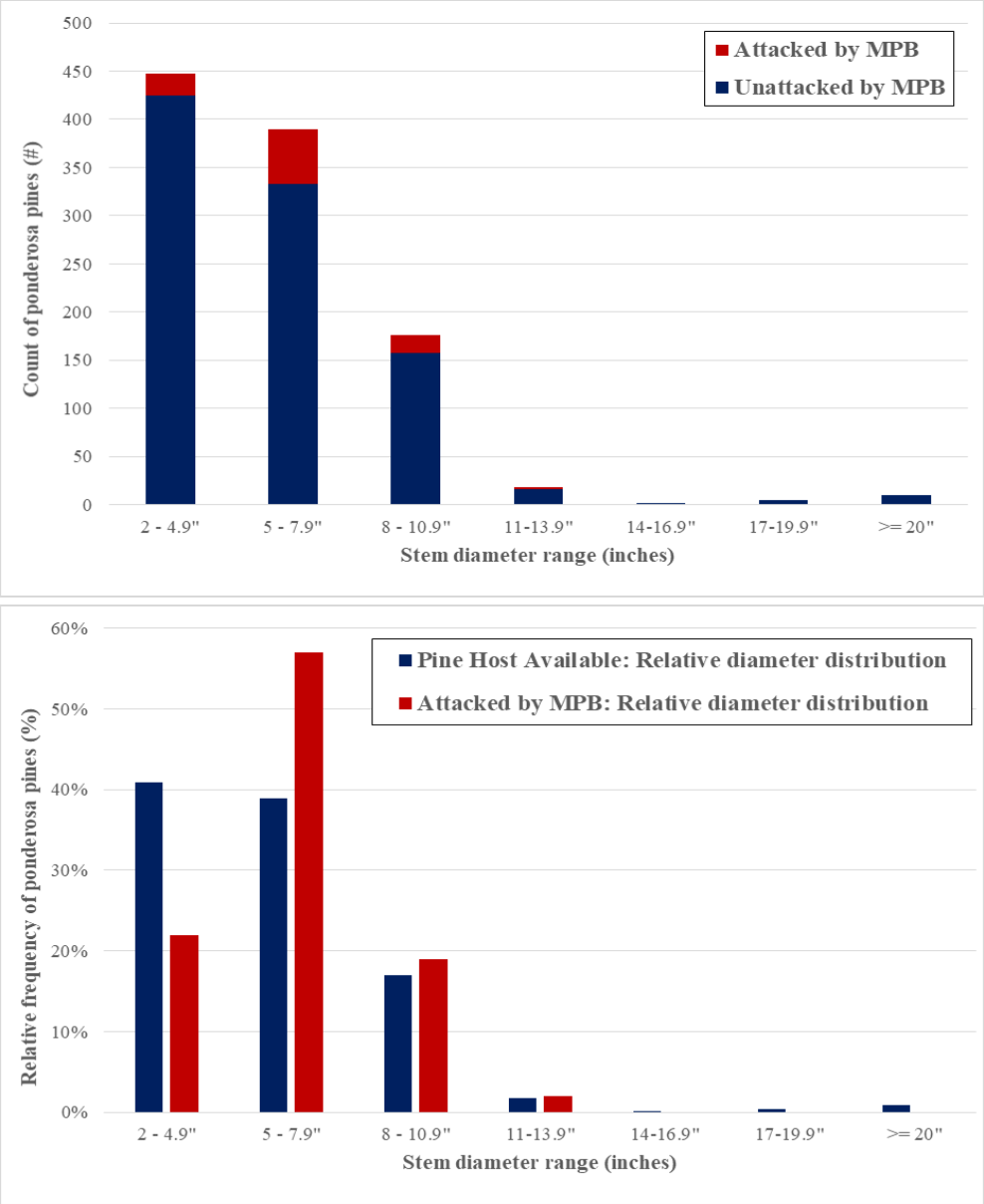

Figure 4. Histograms depicting across all plots a) total number of ponderosa pines attacked and unattacked by MPB from 2010-2014 (top-chart) and b) the relative distribution of MPB-attacked and available host within diameter classes (bottom-chart).

Discussion

Data from this study are presented to identify forest attributes associated with susceptibility and resistance to MPB-attack in young ponderosa pine stands. Severe (>30%) tree mortality occurred in denser plots where forest structures exceeded 172 SDI or 63 BA and where QMD ranged from 4.7-7.3". These data points document forest structures that were not resistant to MPB-attack. Moderate severity mortality (10-30%) was documented in plots as low as 124 SDI, or 54 BA, indicating partial resistance at these density levels. There was no MPB activity observed on plots with SDI below 124, suggesting resistance to MPB-attack near 100 SDI. MPB activity occurred in this study's control plots and the 12x12 thinned plots only.

These findings are consistent with recent work suggesting resistance thresholds to *Dendroctonus* spp. mortality where density levels are < 100 SDI for western yellow pine forests. Egan et al. (*in preparation*) suggests residual density targets should fall below this threshold for high-level resistance (defined as having low probability of >10% mortality) based on analysis of 660 plots encompassing >60,000 trees surveyed after exposure to beetle pressure.

Interestingly, MPB-attacks occurred primarily within 5-7.9" diameter class in which trees were attacked disproportionately higher than expected based on their availability. Larger trees (≥ 14" DBH) in the study area were attacked disproportionate to their availability and were resistant as none were killed by MPBs. This is likely as larger trees, while being preferred reproductive host for bark beetles and associated with higher fecundity rates, have greater above and below-ground growing space that allows for relatively greater drought avoidance and resistance capacity (Oliver and Larson 1996; see Egan et al. 2016 for stem diameter and resistance discussion).

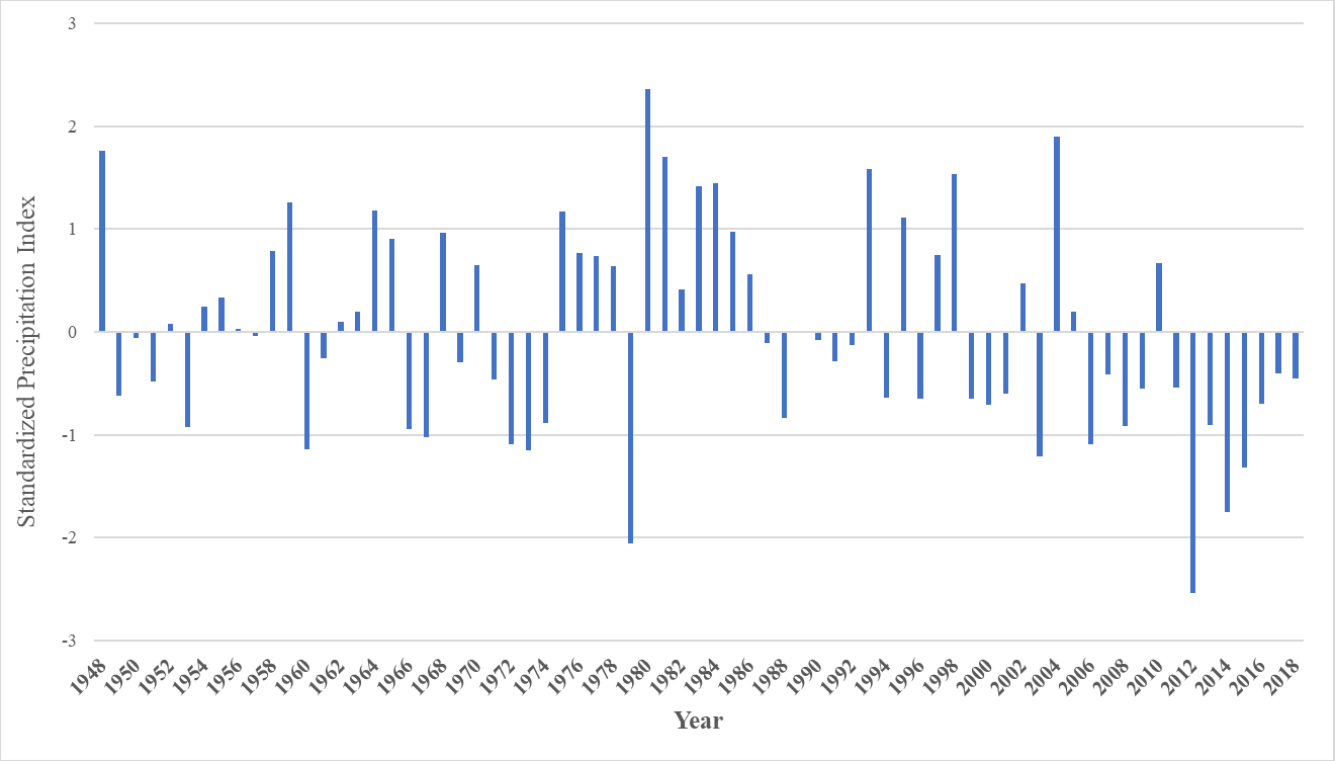

Figure 5. Standardized precipitation index for summer months (May-September) in Lake Como area, 1948-2018. Values -1 to 1 represent 'neutral' conditions; > 1 wet conditions; and < -1 dry conditions (Guttman 1999).

Bark beetle activity was documented in this study area from 2010-2014 when summer precipitation conditions ranged from neutral to dry based on standardized precipitation index data specific to the Lake Como area (Figure 5, Guttman 1999). Overall, drought conditions were generally considered mild during

this period and this MPB outbreak did not transition from an incipient to an epidemic population phase when beetle-attacks often progress from small to large-diameter pines (Egan et al. 2016). Thus, resistance reported in larger pines (≥ 14" DBH) should only be considered within the bounds of a short-lived MPB outbreak, associated with acute dry weather conditions, that was limited to incipient population levels. We anticipate larger pine resistance would diminish in conjunction with severe drought conditions.

Assessment of MPB-caused mortality rates by diameter class within ponderosa pines on the Helena National Forest (HNF) from 2006-2012 yielded similar findings of greater resistance, and reduced mortality rates, within larger diameter pines (Randall et al. 2011; Figure 6). However, drought conditions on the HNF facilitated MPB outbreak development into an epidemic phase and resistance was enhanced for stems diameters ≥20" DBH. This showcases that ambient drought conditions, which vary in duration and severity across space and time, can influence ponderosa pine resistance differently within each MPB outbreak event.

Figure 6. Percent Ponderosa Pine Mortality Caused by Severe MPB Population Pressure by Diameter Class from 2006-2012, Warm Springs Analysis Area, Helena National Forest

Diameter Class	Percent Mortality
5 - 9.9"	48%
10 - 14.9"	55%
15 - 19.9"	53%
20 - 24.9"	38%
> 25"	20%

* Data collected in 48x intensified grid and summarized in Randall et al. (2011)

Conclusions

This study monitored forest health conditions within plots for 10-years following pre-commercial thinnings. After a decade of growth, forested units treated with 18x18 spacing averaged 97 SDI which is lower than the high-level resistance threshold suggested at < 100 SDI (Egan et al., *in preparation*). Units thinned to a 12x12-foot residual spacing grew to an average of 154 SDI (non-pruned), or 127 SDI (pruned), and some plots experienced severe MPB-caused mortality during the study period. Thus, this study suggests benefits of the wider spacing in the 18x18 plots, compared to 12x12 residual spacing targets, in providing for stand density levels that can promote resistance for at least a decade.

Documentation of no MPB-attacks in the 12x12 spacing (with pruning) warrant further investigation for potential microclimate benefits that reduce bark beetle habitat suitability. However, these treatment units were not challenged by localized MPB pressure from adjacent, paired-plots as occurred with the 18x18 treatments. Thus, these treatments may have exhibited 0% mortality rates due to unequal distribution of MPB population pressure rather than a treatment effect.

Furthermore, MPB activity occurred in a plot with QMD levels as low as 3.4" with moderate mortality occurring at 4.0" QMD. Severe mortality was documented in a plot with 4.7" QMD. These findings suggest stands with pine QMD as low as 4" were susceptible to MPBs. These data can inform susceptibility criteria used for the FHP-administered Western Bark Beetle program which provides funding to reduce forest susceptibility to bark beetles.

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